SSERVI-ESF14-084

Author: ALEXANDER BASILEVSKY

POSTER

Geology

Survival times of meter-sized rock boulders on the surface of bodies without atmospheres

We consider the issue of the survival times of meter-sized rock boulders on the surface of bodies without atmospheres. The approach we use was tested in our recent work1 and it is based on thee consideration of the spatial density of boulders on the rims of small lunar craters of known absolute age. In that study1 it was assumed that major factor and process involved in boulder destruction is catastrophic disruption by meteorite impacts. The potential role of diurnal temperature cycling2 was mentioned but not studied. In this analysis, we review the lunar results as a staring point and we then discuss the potential role of thermal cycling. We show that it is less important then disruption by meteorite impacts. Finally, we analyze the meteorite bombardment environment in terms of projectile flux and velocities and based on this we estimate survival times of meter-sized boulders on a range of bodies without atmospheres.1Basilevsky et al. (2013)2Delbo M. et al. Thermal fatigue as the origin of regolith on small asteroids. Nature, 508, 233-236 (2014).

Author: KRISTEN BENNETT

Geology

ORAL

Inferred Variable FeO Content in Medium-Sized Lunar Pyroclastic Deposits from LRO Diviner Data

Lunar pyroclastic deposits (LPDs) are low albedo features that mantle underlying terrain (Gaddis et al. 1985). They are high priority targets for science and exploration as they are believed to originate from and therefore reflect the composition of the deep lunar interior (NRC, 2011). They are also the best potential resource of oxygen out of any Apollo samples (Allen et al. 1996). Historically, LPDs have been divided into regional versus local categories (Gaddis et al. 2003). The large (>1000 km2 area) regional deposits are deeply sourced (>400 km deep) and result from fire fountaining. Small (<1000 km2) local deposits are thought to result from Vulcanian eruptions in which magma is slowly emplaced beneath the surface until enough volatiles exsolve and the high pressure causes an explosion. Bennett et al. (2013) identified a local deposit (674 km2 area) that may have resulted from both Vulcanian activity and fire fountaining. This deposit potentially represents a new intermediate class of LPDs that straddles the interface between the two formation mechanisms. The deposit also exhibits the highest inferred FeO wt.% of any known lunar glass. In this work we investigate the inferred FeO abundances of other medium-sized deposits to characterize this potential new class of deposits and understand the magnitude of variations in inferred FeO among pyroclastic deposits. We use the method of Greenhagen et al. (2010) to calculate the wavelength of the Christiansen Feature (CF) from Lunar Reconnaissance Orbiter Diviner Lunar Radiometer instrument thermal-infrared observations for four medium-sized deposits. From the CF values, we estimate each deposit's FeO abundance using the method of Allen et al. (2012). The four LPDs that we examined (Oppenheimer South, Beer, Cleomedes, and J. Herschel) all have average CF values from 8.22-8.28 microns, corresponding to FeO abundances of ~10-15 wt.%. All of these values are within the range and uncertainties of FeO abundances measured in Apollo samples. As previously identified, the Oppenheimer South deposit exhibits an area of enhanced CF values (8.49 microns) that, if the methods of Allen et al. (2012) can be extrapolated, correspond to a highest observed ~30 wt.% FeO. Moon Mineralogy Mapper near-infrared spectra indicate that this area is glass-rich as opposed to olivine-rich. While we are still investigating the nature of the high CF wavelength in Oppenheimer South, spatially-resolved observations there and (to a smaller degree) in our other study sites, shows that FeO wt.% can vary within LPDs. Thus, obtaining only the average FeO abundance over a large area may not be adequate to understand global variation. The magnitude of Oppenheimer South's CF variability, if due to actual surface variations rather than calibration artifacts or spectral mixing, could indicate that it is a unique deposit and not part of a new mid-sized class of deposits. The higher value could be a result of its location within the South Pole Aitken Basin and exsolution of more deeply sourced magma due to the thin crust there.

Author: JACOB BLEACHER

Geology

ORAL

Remote, In Situ, and Synchrotron Studies for Science and Exploration (RIS4E) Field Campaigns

The RIS4E team will conduct yearly geologic field campaigns as a means of evaluating instrument design and best practices for their use during future HEOMD exploration of Target Bodies. The design and use of portable instruments that provide real-time analytical data to astronauts and a science team have been largely unexplored despite a heritage of useful analog tests. To address this identified need for future SMD-HEOMD exploration, we will perform three main tasks that involve field geology at the December 1974 (D1974) flow on K_lauea Volcano, HI, and the Potrillo Volcanic Field (PVF), NM. Field work at these sites will use currently available portable analytical science instruments to provide new scientific insights into the volcanic and igneous development of these lunar analog volcanic terrains, pursuing three tasks: 1) characterizing precise field location, or topography, and subsurface structure, 2) characterizing geochemical and mineralogical details that are not decipherable from remote measurements, and 3) evaluating results to provide insights into the design and use of portable/handheld SMD instruments during HEOMD exploration of SSERVI Target Bodies.The field sites selected for our field campaigns enable scientific studies of concepts relevant to planetary exploration. At the Hawaiian lava flow field we will test if sinuous channels can form when preferred pathways drain from within an active sheet flow. Such channels or rilles would lack levees and display deep channels with steep walls. Such a process could explain lunar rille formation without the formation of lava tubes, thereby lacking radiation safe havens. At the New Mexican lava flows the RIS4E team will characterize pits that are associated with lava tubes, and those that formed within inflated sheet flows. At both sites the team will use precise surface location information (topography) and knowledge of subsurface structure (Ground Penetrating Radar) to provide new scientific insights that help differentiate tube-related from sheet inflation-related pit formation as a means of better interpreting the lunar volcanic history and identifying radiation safe havens. Thus, the RIS4E team will determine best approaches to coupling surface topographic data with GPR data to best characterize the near-surface structure of SSERVI Target Bodies.High resolution spectral observations of the Moon and studies of lunar meteorites show unique lithologies that were not observed at coarser resolution remote observations. Similarly, laboratory analyses of samples collected from locations that are identified as spectral end member units in the D1974 Hawaiian lava flow show significant spectral variability, suggesting that the remotely derived spectrum was better represented as an average of the individual samples collected rather than a match to any single sample. We will characterize geochemical and mineralogical variability across both field sites using currently available, portable instruments. This will enable the RIS4E team to evaluate best practices for developing and incorporating hand-held SMD geochemistry/mineralogy instrumentation into future HEOMD sampling strategies for Target Bodies.

SSERVI-ESF14-087

Author: JOSHUA CAHILL

POSTER

Geology

SURVEYING THE SOUTH POLE-AITKEN BASIN MAGNETIC ANOMALY FOR REMNANT IMPACTOR METALLIC IRON

For decades it has been known that portions of the lunar crust are strongly magnetized [1-4]; yet the origin of magnetization is not understood. Difficulties discerning a source for these anomalies begin with most of them having no consistent association with geologic structures. Impact basins and ejecta, and antipodes are geologic structures that sometimes associate with magnetic anomalies [5], but most are weak relative to the global dynamic range. Further, many of these same structures do not show magnetic anomalies. It is also difficult to reconcile the strengths of many of these anomalies with lunar samples, as most lunar materials are weakly magnetic relative to terrestrial materials. Magnetic measurements of mare basalt and pristine highlands rock show weaker magnetism relative to mid-ocean ridge basalts (~3 orders of magnitude) [6]. Another complication is the mineralogy of lunar magnetic anomalies is not rigorously constrained. As a result, it is difficult to discern if the magnetization is derived from crystallization or from impact shock [7, 8].Wieczorek et al. [9] suggest that magnetic anomalies on the southern farside of the Moon are attributable to remnant metallic iron from the impactor that created South Pole-Aitken basin (SPA) [9]. They argue that the distribution of modeled projectile materials roughly coincide with the distribution of magnetic anomalies near the northern rim of SPA. Wieczorek et al. [9] note that chondritic projectiles are approximately two times more magnetic than average lunar crustal materials. If the SPA-forming projectile were similar to an undifferentiated chondrite, then the thickness of the ejecta needed to account for the magnetism of materials north of SPA would only need to be a few hundred meters thick. This thickness could be less if the projectile were differentiated into core, mantle, and crustal components. We evaluate this hypothesis combining Lunar Prospector Gamma Ray Spectrometer (GRS) and Clementine reflectance (CSR) FeO products. Our results are ultimately inconclusive. Delta FeO (i.e., GRS-CRS) is higher north of SPA as observed by GRS and might suggest detection of remnant metallic iron. However, excess GRS FeO is evenly distributed throughout the farside highlands. Any remnant high-Fe materials would need to cover the farside highlands in ejecta, and then avoid being covered with a subsequent 10 cm of regolith from impact processes. Furthermore, _FeO and magnetic anomalies are not spatially correlated and do not show corresponding dynamic intensity ranges. Ultimately, due to the old age of SPA and subsequent impact mixing, it may be that any magnetic materials are now too deep to be detected by either instrument. Acknowledgments: Supported by NASA LASER grant NNH09AL71I.

Author: KERRI DONALDSON HANNA

POSTER

Geology

Thermal Infrared Studies of Lunar Soils: Characterizing Spectral Effects due to Simulated Lunar Conditions and Packing

Apollo soils [e.g. 1-3] as well as basaltic rocks [4] have been well-characterized across the visible- to near-infrared wavelengths including the effects of particle size, mineralogy, mineral chemistries, ilmenite content and space weathering on their spectra. These laboratory analyses provided ground truth to remote sensing observations from Earth-based telescopic observations and spacecraft observations like those from Clementine, Galileo, Lunar Prospector, SELENE, and Chandrayaan-1 as well as providing key insights into the composition and evolution of the lunar surface. The Diviner Lunar Radiometer, a thermal infrared (TIR) radiometer onboard the Lunar Reconnaissance Orbiter, has been orbiting the Moon since 2009. Quantitative analyses of these multispectral TIR data have required the characterization of Apollo samples across TIR wavelengths. The near-surface vacuum environment of airless bodies like the Moon creates a thermal gradient in the upper hundred microns of regolith. Lab studies of particulate rocks and minerals as well as selected lunar soils under vacuum and lunar-like conditions have characterized the effects of this thermal gradient on TIR spectral measurements [e.g. 5-9]. Such lab studies demonstrate the high sensitivity of TIR emissivity spectra to environmental conditions under which they are measured. Furthermore, TIR lab studies have demonstrated the spectral effects of packing on TIR spectral measurements [e.g. 5,10].In this work, an initial set of TIR emissivity measurements of bulk lunar soil samples will be made in the Asteroid and Lunar Environment Chamber at Brown University [11] and the Simulated Lunar Environment Chamber at the University of Oxford [8]. In each chamber, the lunar environment is simulated by: (1) pumping the chambers to vacuum pressures (<10-3 mbar), which is sufficient to simulate lunar heat transport processes within the sample, (2) cooling the chambers with liquid nitrogen to simulate the cold space environment that the Moon radiates into, and (3) heating the samples from below, above, or both to set up thermal gradients similar to those experienced in the upper hundreds of microns of the lunar surface. These laboratory measurements of bulk lunar soil samples will be compared with Diviner data to understand: (1) how to accurately simulate conditions of the near-surface environment of the Moon in the lab and (2) the difference between returned samples and undisturbed lunar soils in their native setting. Both are integral for constraining the composition and physical properties of the lunar surface from current and future TIR datasets.

Author: ABIGAIL FRAEMAN

ORAL

Geology

Compositions of Phobos and Deimos: The View from Visible to Near Infrared Spectroscopy

The compositions of Mars' moons, Phobos and Deimos, are a direct indicator of the mechanism that formed them. One of the longstanding questions of planetary science is whether the moons formed in situ around Mars, either through co-accretion or giant impact, or if they are captured asteroids originating from elsewhere in the solar system [1]. The key to unlocking this mystery will be to determine whether the moons are composed of materials native to the Martian system or if they are made of something that could only have arrived from another location [2]. Disk-resolved, visible to near infrared hyperspectral observations of Phobos acquired by OMEGA at a range of lighting and viewing geometries are fit with a Hapke photometric function to solve for the single particle phase function. This knowledge is used to derive single scattering albedos of CRISM and OMEGA Phobos and CRISM Deimos observations, which can be projected to any viewing geometry for direct comparison with laboratory spectra. Fe electronic absorptions diagnostic of olivine and pyroxene are not detected. A broad absorption centered on 0.65 μm within the red spectral units of both moons is seen, and this feature is also evident in telescopic, Pathfinder, and Phobos-2 observations of Phobos. A 2.8 _m metal-OH combination absorption on both moons is also detected, and this absorption is shallower in the Phobos blue unit than in the Phobos red unit and Deimos. The strength, position, and shape of both features are similar to absorptions seen on low-albedo primitive asteroids. Two end-member hypotheses could explain these spectral features: the presence of highly desiccated Fe-phyllosilicate minerals indigenous to the bodies, or Rayleigh scattering and absorption of small iron particles formed by exogenic space weathering processing, coupled with implantation of H from solar wind [3]. Both end-member hypotheses may play a role, and in situ exploration will be needed to ultimately determine the underlying causes for this pair of spectral features. Phobos' and Deimos' low reflectances, lack of mafic absorption features, and red spectral slopes are incompatible with even highly space weathered chondritic or basaltic compositions. These results, coupled with similarities to laboratory spectra of Tagish Lake (possible D-type asteroid analog) and CM carbonaceous chondrite meteorites, show that Phobos and Deimos have primitive, carbonaceous-chondrite like compositions. If the moons formed in situ rather than by capture of primitive bodies, primitive materials must have been added to the Martian system during accretion or a late stage impact [4]. References: [1] Burns, 1992, Mars, Univ. Arizona Press, [2] Murchie et al., 2014, Acta Astronautica, 93, 475-482, [3] Fraeman et al., 2014, Icarus, 229, 196-205, [4] Fraeman et al., 2012, JGR, 117.

Author: W. BRENT GARRY

ORAL

Geology

The Formation of Pits in Volcanic Environments: Analogs and Lessons for the Future Planetary Exploration

Introduction: Martian and lunar pits with overhanging ledges might be connected to caves or lava tubes, and these caves could be used as safe havens for astronauts as protection from high radiation Solar events. Terrestrial pits found in volcanic terrains can form through several scenarios and still appear morphologically similar to the Martian and lunar pits. However, lava flow inflation (among other methods) also form pits with overhanging ledges that appear to connect to subsurface void space. Yet, field observations show that inflation pits do not connect to caves.Analogs: We have conducted field work in basaltic environments in Hawaii, New Mexico, and Idaho and observed pits at each site. Not every pit we have observed leads to an extensive, interconnected system of tubes or void space. For example, within the McCartys lava flow circular pits form within the inflation plateaus and have overhanging ledges, rubbly bottoms, but drained-out tube systems are not present. In other terrains (e.g., Kilauea Southwest Rift Zone (SWRZ), HI; Cerro Rendija, NM), even though a lava tube is present beneath the surface, access to the tube has been blocked by debris. Ideal field sites (e.g. Mauna Loa SWRZ) exhibit visible layering in the upper walls and an accessible tube system. Exploration: The discovery of subsurface voids on both the Moon and Mars could lead to potentially ground breaking missions. LiDAR can provide precise measurements of pit morphology and Ground Penetrating Radar (GPR) can provide reconnaissance of the subsurface around the pit. NASA has funded a study of volcanic pits via the SSERVI RIS4E team over the next 5 years to investigate this issue. Prior to any mission (human or robotic), it will be important to understand the geologic context of these pits. Differentiating tube or rille-fed from sheet-fed flows is crucial for developing informed predictions of which pits might be linked to tubes or caves. Furthermore, assessing the surface and subsurface expressions of pits and caves (lava tubes) is critical for future Human Exploration Operations Mission Directorate (HEOMD) strategies that might include these geologic features for radiation protection.

Author: BENJAMIN GREENHAGEN

ORAL

Geology

Compositional Ground Truth for the Diviner Lunar Radiometer: Comparing Apollo Sites and Soils

Apollo landing sites and returned soils afford us a unique opportunity to “ground truth” Diviner Lunar Radiometer compositional observations, which are the first global, high resolution, thermal infrared measurements of an airless body. The Moon is the most accessible member of the most abundant class of solar system objects, including all SSERVI target bodies. Additionally, the Apollo samples returned from the Moon are the only extraterrestrial samples with known spatial context. Here we compare Diviner observations of Apollo landing sites and compositional and spectral laboratory measurements of returned Apollo soils.Diviner, onboard NASA’s Lunar Reconnaissance Orbiter, has three spectral channels near 8 μm that were designed to characterize the mid-infrared emissivity maximum known as the Christiansen feature (CF), a well-studied indicator of silicate mineralogy. It has been established previously that thermal infrared spectra measured in simulated lunar environment (SLE) are significantly altered from spectra measured under terrestrial or martian conditions, with enhanced CF contrast and shifted CF position relative to other spectral features. Therefore only thermal emission experiments conducted in SLE are directly comparable to Diviner data. Here we present data collected at the University of Oxford Simulated Lunar Environment Chamber (SLEC) and JPL’s Simulated Airless Body Emission Laboratory (SABEL).With known compositions, Apollo landing sites and soils are important calibration points for the Diviner dataset, which includes all six Apollo sites at approximately 200 m spatial resolution. Differences in measured CFs caused by composition and space weathering are apparent in Diviner data. We find that analyses of Diviner observations and SLE measurements for a range of Apollo soils show good agreement, while comparisons to thermal reflectance measurements under ambient conditions do not agree well, which underscores the need for SLE measurements and validates the Diviner compositional measurement technique.Diviner observations of Apollo landing sites are also correlated with geochemical measurements of Apollo soils from the Lunar Sample Compendium. In particular, the correlations between CF and FeO and Al2O3 are very strong, owing to the dependence on the feldspar-mafic ratio. Our analyses, an extension of earlier work, support findings that Diviner data may offer an independent measure of soil iron content from the existing optical and gamma-ray spectrometer datasets.

Author: JAMES HEAD, III

Geology

ORAL

Lunar Geoscience: Key Questions for Future Lunar Exploration

The last several decades of intensive robotic exploration of the Moon has built on early Apollo and Luna exploration to provide fundamental knowledge of Earth's satellite and an excellent perspective on the most well-documented planetary body other than Earth. This new planetological perspective has raised substantial new questions about the nature of the origin of the Moon, its early differentiation and bombardment history, its internal thermal evolution, the production of its secondary crust as exemplified by the lunar maria, and tertiary crust as potentially seen in steep-sided domes and impact melt differentiates, the abundance of interior volatiles and their role in volcanic eruptions, and the abundance of surface volatiles and their concentration in polar regions. On the basis of this new information, a series of specific outstanding geoscience questions can be identified that can serve as guides for future human and robotic exploration. These include: 1) What is the nature and abundance of impact melt seas and what rock types do they produce upon differentiation and solidification? 2) Where are lunar mantle samples located on the lunar surface and what processes are responsible for placing them there? 3) What processes are responsible for producing the silica-rich viscous domes, such as those seen at Gruithuisen? 4) What are the volatile species involved in the emplacement of lunar pyroclastic deposits and what clues do they provide about deep magmatic volatiles and shallow volatile formation processes? 5) How do we account for the differing characteristics of regional dark mantling pyroclastic deposits? 6) When did mare basalt volcanism begin (earliest cryptmaria) and how and where is it manifested? 7) Was there extensive volcanism and resurfacing prior to mare basalt volcanism; if so, what is its origin and how is it manifested? 8) Are there other shallow magmatic intrusions besides floor-fractured craters, and if so, what is their origin? 9) What clues can we derive from the geology and gravity structure of floor-fractured craters concerning the modes of emplacement and magmatic evolution of shallow intrusions; does differentiation and volatile build-up take place? 10) What are the factors that explain the formation of complex craters, peak-ring basins and multi-ring basins? 11) What are the ages of key multi-ring basin impact melt sheets and how do they help to determine lunar impact chronology and flux? 12) How can lunar crustal density and thickness structure revealed by GRAIL be related to geological impact, magmatic and tectonic processes? 13) What is the origin, distribution and mode of emplacement of polar and circum-polar volatile deposits? 14) What is the origin of central peaks and their often unusual mineralogy and how do we account for the evidence for heterogeneous melt composition and structure? These and other major geoscience questions form the basis for robust and exciting future international robotic and human exploration and sample return missions. A series of candidate sites of interest are identified that can address these questions.

Author: SCOTT HUGHES

Geology

ORAL

Combined Geomorphic and Petrologic Models of Lava Flow Surfaces, Pyroclastic Ejecta and Volcanic Stratigraphy as Planetary Analogs

Geomorphology of volcanic features, widely used to interpret eruptive history and magma generation, often lead to extended evaluations of planetary body evolution. Investigations typically based on close field observations and/or remote sensing imagery, are used in conjunction with geochemical and petrographic information to make such broad interpretations.Research by the FINESSE team (PI Jennifer Heldmann) aims to decipher and quantitatively model volcanic features that represent a wide variety of morphological types at Craters of the Moon National Monument and Preserve (CRMO), and immediate surroundings on the eastern Snake River Plain (ESRP). The region was selected for the variety and relative freshness of the surfaces (~2 – 15 ka eruptions) and close apparent relation between composition and geomorphology, ranging from basalts with pahoehoe and a'a surfaces to evolved trachyandesites with block flow surfaces. Surface types often change within a single flow over a relatively short distance. Comparison to similar fresh features in Hawai'i in conjunction with the RIS4E team (PI Timothy Glotch), and other regions of active volcanism will enable a broader assessment of myriad complexities that go beyond the well-known classification and sub-classifications of lava flow types, and possibly lead to more detailed comparison with impact-generated melts and their accompanying lava flows.Our preliminary research focuses on the classification of morphotypes of lava flow surfaces based on close field examination, hand-held and UAV-mounted imagery, sub-cm LiDAR, and differential GPS to quantify models of surface roughness and the spacing of irregularities in relief, thickness, and flow unit forms. Our study also aims to investigate, by similar means, pyroclastic fields, tephra-coatings on lavas, large "rafts" of congealed tephra blocks carried several km on lava flow surfaces, and blocks (positions and masses) ejected by volatile-related explosive eruptions. Geomorphic models are being addressed in conjunction with geochemical and petrographic attributes. The intention is to produce quantifiable models that can be used to interpret features on SSERVI target bodies involving various exploration techniques (robotics, remote sensing, on-site visits by astronauts).Preliminary tasks address (1) classification and spatial distribution of volcanic constructs; (2) rock types, dimensions, volumes, and relative proportions comprising each construct; (3) ejecta distribution at explosive pit craters; and (4) the variability in slope and surface roughness of lava flows. Extended work focuses on tephra and lava stratigraphy representing separate eruptions or pulses within a single eruption, relations of fissures and extension cracks to dike injection vs. crustal stresses, and the distinction between impact melts and breccias from volcanic equivalents.Our research will lead to the development of quantified models for autonomous feature recognition and navigation as well as assessment of target areas for resource exploration. Moreover, the characterization of how eruptive and emplacement mechanisms affect the morphology can improve the effectiveness of planetary surface evaluation and the interpretation of volcanic and impact history.

Author: MIKHAIL IVANOV

POSTER

Geology

Boguslawsky Crater: Analysis of a High-Latitude Impact Crater Sampling Pre-South Pole-Aitken Basin Crust as a Candidate Landing Site

Boguslawsky Crater (73oS, 43oE, ~100 km in diameter) is an ancient high southern latitude crater that is in the region that might contian polar volatiles. Neither Boguslawsky itself, however, nor its close surroundings show evidence for the suppression of the neutron flux from the surface. This means that in this region possible accumulation of hydrogen-bearing phases in upper regolith is below the level of detection by the LEND instrument, ~100 ppm, and analysis of volatiles in near-surface regolith is less likely. Boguslawsky is located within heavily cratered terrain that lies on a portion of the southern rim of the SPA basin. Thus, at Boguslawsky there is a possibility to analyze materials that compose the SPA rim and likely represent some of the oldest rocks on the Moon, which formed prior to the SPA impact event.We mapped the interor and floor of Boguslawsky, focusing in on two areas, 15 x 30 km each, at 72.9oS, 41.3oE (western landing ellipse) and at 73.9oS, 43.9oE (eastern landing ellipse) Three morphologically distinctive units are the most abundant within these areas: rolling plains (rp), flat plains (fp), and ejecta from crater Boguslawsky-D (ejf), which is on the eastern wall of Boguslawsky. The distinctly low depth/diameter ratio and interpretation of the possible structure of the crater interiors suggest that flat and rolling plains likely represent ejecta from remote and distant sources and have accumulated on the original floor of Boguslawsky since its formation. There is no positive evidence (dark halo craters, cryptomaria, mafic anomalies, etc.) for plains of volcanic origin modifying the crater floor. These materials are thus likely to be a combination of excavated pre-SPA crust and secondary ejecta material derived from distant craters. The nature of these units makes them desirable targets for potential sampling of ancient deep crust, contaminated to some degree by externally-derived ejecta.Ejecta from Boguslawsky-D comprises about 50% of the eastern ellipse and are among the stratigraphically youngest materials that were ejected from the Boguslawsky wall and re-deposited on the floor of the crater. The Boguslawsky wall cuts the ancient highlands that correspond to the southern portion of the SPA rim. Thus, ejecta from Boguslawsky-D likely consist of materials that form the SPA rim and, thus, represents a target of highest scientific priority on the Boguslawsky floor for sampling uncontaminated pre-SPA material.We have analyzed this region as a candidate landing site for future in situ and sample return missions. Neither the frequency distribution of slopes (30-m baseline), nor the rock (fragments larger than ~0.5 m) abundance on the surface of Boguslawsky-D ejecta, suggest that this unit is unsafe for landing.

Author: LAUREN JOZWIAK

Geology

ORAL

Lunar floor-fractured craters: constraining the timing of intrusion formation within the lunar volcanic history

Lunar floor-fractured craters (FFCs) are a class of 170 lunar craters characterized by shallow, fractured floors and associated morphologic features such as moats, mare and pyroclastic deposits. These craters are formed by stalling of a dike beneath the crater, and subsequent sill formation which uplifts and deforms the overlying crater floor. The geographic distribution of FFCs indicates that they preferentially form near the edges of lunar basins, although a subset of the FFC population is located in highland areas. The nature of FFC intrusions is an important factor to the understanding of the intrusive volcanic history of the Moon. Dating of these intrusions may offer additional insight into the chronology and associated mode (i.e. intrusive vs. extrusive) of lunar volcanism. We investigate the timing of FFC formation and examine whether or not this intrusive volcanic component formed in association with the main period of extrusive lunar volcanism, or if the intrusions span the entirety of lunar history with no spatial or temporal correlation to extrusive volcanic features. The stratigraphic ages of the FFC host craters span from the pre-Nectarian through the Eratosthenian, with a single example of a putative Copernican aged crater, Taruntius. The majority of the host craters are Nectarian to Imbrian in age. There are six FFCs whose interiors have been partially embayed by mare deposits following their intrusion events; these mare deposits are Imbrian in age. Host crater age places an older bound on the intrusion age for a given intrusive event, and the few examples of post-deformation mare embayment place a younger bound on intrusion age. Plotting the spatial distribution of the host crater ages reveals a link between ages of mare basalt deposits (via crater size-frequency distributions) and the host crater ages of regional FFC clusters. For example, there are several FFCs surrounding the Nectaris basin, all of which have a Nectarian host crater age. No stratigraphically younger craters around Nectaris have been deformed by the intrusive volcanic processes affecting FFCs; however, a paucity of younger craters adjacent to the basin edge means the intrusive activity cannot be constrained to the Nectarian. Indeed, the general lack of Nectarian-aged mare deposits combined with the Imbrian-aged crater degradation surface ages in Nectaris suggest that the FFC intrusions surrounding Nectaris formed during the Imbrian period. Many of the FFC host craters on the western edge of Oceanus Procellarum are Imbrian in age, as are the mare units located in that region. This correspondence between regional mare basalt ages and FFC host crater ages suggests that the intrusions which formed FFCs were emplaced during the main phase of extrusive volcanism on the Moon. Additionally, tectonic deformation associated with basin mare filling and loading shows close spatial correlation to FFC locations. Models of basin flexure have postulated that the extensional regime present in peripheral basin regions should be favorable to dike ascent, consistent with the suggestion that some FFCs are the surface manifestation of dikes propagated in response to basin filling and flexure.

Author: MARY KERRIGAN

Geology

ORAL

The West Clearwater Lake impact structure as a planetary analogue.

Impact cratering is the dominant geological process on the Moon, asteroids, and moons of Mars. The exploration and study of terrestrial craters is essential therefore to understand the origin and emplacement of impactites, the history of impact bombardment in the inner Solar System, the formation of complex impact craters, and the effects of shock on planetary materials. The West Clearwater Lake impact structure (WCIS) in northern Quebec, Canada (56°10 N, 74°20 W) is one of the field sites chosen by the FINESSE (Field Investigations to Enable Solar System Science and Exploration) team as an analogue to the SSERVI target bodies. We will present here an overview of the main scientific targets at this site, remote sensing analysis, and traverse planning for the first field expedition.WCIS is part of a rare example of a double impact structure, formed ~290 Mya, expressed as two adjacent circular lakes. WCIS is approximately 30 km in diameter and has an inner ring of islands (16 km diameter) representing the eroded remnants of the central uplift. Bathymetric data show that East Clearwater Lake (21 km diameter) also has a smaller, submerged, central uplift. The target lithologies for this impact crater include Precambrian granitic gneiss, granodiorite, and quartz monzodiorite of the Canadian Shield with cross cutting diabase dikes. Blocks of Ordovician limestone also occur in the melt rocks on the central islands.Fieldwork at WCIS will commence in August 2014 and will contribute to research areas including the modification of impact rocks and the structural mechanics of crater formation. Understanding the nature and emplacement history of impactites will involve the study of the impact melt rocks and breccias on the central island of WCIS, locating the contacts between melt-rich deposits, melt-poor lithic breccias, and target rocks. By examining their field relationships and sampling each of these lithologies we will be able to determine the local geologic setting. Another important research question addressed here relates to the effects of the volatile content of the target rock during the impact cratering process, and on the potential for an impact induced hydrothermal system. The energy released by a hypervelocity impact generates heat and mobilises volatiles and fluids in the near and subsurface. This activity creates environments that have been identified as hosting life in terrestrial craters and proposed as potential habitats for life on Mars and other planets. While secondary minerals have been identified at WCIS, no study has focused on the hydrothermal system of this crater. For questions relating to cratering mechanics we use remote sensing datasets as well as field techniques. Visible images at various spatial resolutions will provide important morphological and structural information that will be vital towards determining the various crater settings. This will be supplemented by DEMs and radar data to ascertain the structure and morphometric properties of the structure. In the field we will conduct lithological and structural mapping of the central islands within WCIS, which are interpreted as the central uplift.

Author: ALEXANDRA MATIELLA NOVAK
POSTER

Geology

Compositional Characterization of Lunar Impact Melt Flows Using Moon Mineralogy Mapper (M3)

Numerous impact melt flow deposits have been identified exterior to impact crater rims on the Moon [e.g., Hawke and Head, 1977; Denevi et al., 2012; Stopar et al., 2014; Neish et al. 2014]. We focus our attention upon examination of a portion of the 146 impact melt flows exterior to crater rim crests identified and described by Neish et al. [2014]. While many of these craters were initially discovered with optical imagery, Neish et al. [2014] identified many additional impact-melt flows using Mini-RF data. Numerous impact melt flows normally not visible to optical instrumentation are visible in S-band (12.6 cm) radar because their physical properties are distinct from their surroundings. Here, we further characterize these impact melt flows for their spatial emplacement, mineralogy, and chemistry using Moon Mineralogy Mapper (M3) data to place better constraints on aspects of impact crater processes. In particular, we aim to examine potential influences on impact melt emplacement including: mineral to glass proportions, the depth of excavation of target materials, and any evidence for remnant impactor materials or secondary recrystallization of these materials to different mineral assemblages relative to the surrounding target rock. M3 is useful towards this evaluation because it collected data in 85 spectral bands in the near-infrared ranging from 430 to 3000 nm at 140 to 280 m/pixel and achieved global coverage during the first half of 2009. Several types of near-infrared absorption analyses are appropriate for discriminating lunar deposits of various mineralogies and chemistries. Several initial lunar impact melt flow deposits have recently been examined using M3 data by Kramer et al. [2011], Dhingra et al. [2013], and Woehler et al. [2014]. For example, Dhingra et al. [2013] used a combination of the albedo at 1498 nm, the integrated band depth (IBD) at 2000 nm, and the band depth (BD) at 1900 nm to better characterize the spatial extent and composition of an impact melt flow deposit on the floor of Copernicus crater.Here, in order to further characterize the composition of this database of impact melt flows we utilize similar band and integrated band depth analyses to better discriminate their mineralogy, chemical composition, and the spatial extent of these melt deposits relative to monochromatic optical imagery and S-band data sets. The mineral and chemical composition of these melts will advance our understanding about the physical and chemical processes that aided in the emplacement of these flows subsequent to target impact.

Author: DANIEL MORIARTY

ORAL

Geology

The Diverse Local and Regional Stratigraphy of the South Pole – Aitken Basin

As the oldest and largest well-preserved basin on the Moon, the South Pole – Aitken Basin (SPA) is relevant to a broad range of lunar science topics including the composition, structure, and evolution of the lunar crust and upper mantle, the nearside-farside dichotomy, the absolute ages of lunar impact basins and the late heavy bombardment, and the mechanics of large impact processes. SPA is a high-priority target for future sample return missions, which could address each of these issues. Several focused efforts are underway in order to identify appropriate landing sites. We are currently working with Moon Mineralogy Mapper (M3) hyperspectral data in order to assess mineralogical diversity across the basin and evaluate the diverse local stratigraphy arising from both the SPA impact event and eons of subsequent cratering and space weathering processes. SPA exhibits a mafic-bearing composition with optical properties dominated by pyroxenes. Compositional variations among these pyroxenes are captured in the 1 _m and 2 _m spectral absorption bands as measured by M3. We have developed an approach to identify and characterize the compositions of the most pristine pyroxene-bearing exposures in the basin by measuring the depths and centers of these absorption bands in geologic context. The approach has been validated using a wide variety of laboratory spectroscopic data. Most of the well-defined mafic exposures in SPA are associated with crater structures of varying sizes. We use impact crater scaling laws (specifically regarding excavation, impact melting, and central peak formation) to estimate the origin depth of the exposed materials. By considering several exposures in and around several SPA craters, the local stratigraphy is evaluated. Due to the large size of SPA, the basin-wide stratigraphy can only be evaluated by integrating local geologic context including the regional history of impact cratering and magmatism. From an initial analysis of SPA subregions, several stratigraphic trends are beginning to emerge. Several (but not all) central peaks (which represent the deepest material exposed in a given crater) exhibit a narrow range in pyroxene composition relatively rich in Mg. Wall material (originating from shallower depths) is often of a different composition. The apparent uniformity of the central peak composition suggests the presence of a relatively homogenous Mg-rich zone tapped by these diverse craters. Material with distinctively more Fe- and Ca-rich pyroxenes occurs principally near the center of the basin (e.g., mafic mound). The observed relationships arise from some combination of SPA impact melt heterogeneity, diversity of crust/mantle clasts in basin floor materials, impact melt differentiation, redistribution of materials in subsequent impacts, mare basalt emplacements, and soil development. Analysis of the composition across additional local areas will further constrain the character and origin of the diverse stratigraphy observed in SPA.

Author: ZACHARY MORSE

POSTER

Geology

Analysis of Orientale Basin Ejecta and Evidence for Multistage Emplacement

Orientale Basin is a multi-ring impact structure centered at (266.5º E, -19.5º N) on the western edge of the nearside of the Moon. It is arguably the best-preserved multi-ring basin in the Solar System. The main crater rings (Inner Rook, Outer Rook, and Cordillera) extend approximately 300 km radially from the center of the basin, with ejecta extending an additional 800 km across the lunar surface. Our focus is on the Hevelius formation, or ejecta deposits of Orientale that extend out beyond the Cordillera Ring. Our goal is use new datasets available to achieve a better understanding of ejecta emplacement around multi-ring basins. High resolution, 100 m per pixel images from the Lunar Reconnaissance Orbiter's Wide Angle Camera were utilized to observe and map the Hevelius formation. Our initial analysis is thus far confined to the southwestern quadrant of the basin. Several areas of interest were identified which show noticeably different textures within deposits that lie conformably on the ballistically emplaced ejecta. Using data from the Lunar Orbiter Laser Altimeter, a 3D elevation model was generated to visualize the local topography. The LROC WAC images were then overlain on this 3D framework in order to identify any relationship between various morphologies and topography.Eight features have been identified that display distinct linear features consistent with the viscous fluid mass movement of molten rock. These features show movement down slope, following topographic lows around high elevation obstacles within their path. This morphology is consistent with the appearance and movement of flow structures within one radius of smaller craters. Furthermore, most of the identified structures display preferential orientation away from the center of the impact basin. These features are visibly distinct from the surrounding ballistic ejecta. It is clear that there are no nearby volcanic vents, eliminating the possible subsurface origin of these features. The shallow slopes over which these features extend also point to past molten flow as the source of their texture. Other mechanisms of large-scale material movement such as slumping or dry mass wasting could only be triggered on significantly steeper slopes. We suggest that these eight features are the solidified remains of impact melt flows that originated from the center of the basin. These deposits overlie ballistic ejecta in several locations which requires emplacement after the initial emplacement of the ballistic ejecta. This is consistent with the multi-stage ejecta emplacement model proposed by Osinski et al. (2011). Further mapping with LRO-WAC, NAC, and Mini RF will be undertaken for a more detailed analysis of the potential flow features.

Author: LILLIAN OSTRACH

ORAL

Geology

Detection of Non-Obvious Secondary Craters Through Measures of Crater Density

Interpretation of crater size-frequency distributions (SFDs) assumes that impact cratering is a random process and that the accumulation of craters over time on a surface reflects age. SFDs should only consider primary craters within a region assumed to consist of one geologic unit of uniform age [e.g.,1]; obvious secondary craters occurring in chains or clusters (including herringbone pattern ejecta) and the areas containing them must be excluded. However, recent investigations indicate that secondaries do not always display these typical features [2,3], suggesting that "non-obvious" secondaries dominate SFDs at diameters ≤1km [4]. Here we measured crater density in Mare Imbrium, revealing the presence of non-obvious secondary craters with diameters ranging from 500m to ~2km.Crater SFDs were measured on LROC WAC 100m/pixel mosaics for a region encompassing 2.27_10^5 km^2 within Mare Imbrium. The areal density of impact craters was determined from a point density calculation; output cell size and neighborhood radius were user-defined. Varying neighborhood radius alters the spatial structure observed in the density map. Although smaller neighborhood sizes emphasize statistical variability when considering regional density trends [i.e., too few samples per neighborhood for boundary identification; 5], their usage reveals clustering that may reflect non-obvious secondaries, which can then be verified through morphologic observations. In Mare Imbrium, the majority of grouped craters interpreted as non-obvious secondaries have diameters between 500m to ~850m, although craters as large as 2km were measured. Some crater groupings are within a higher albedo region (ejecta ray) than the surrounding terrain and can be traced back to a probable parent primary [i.e., Copernicus], lending support for a secondary origin. For other crater groupings, size-range distributions estimate the maximum secondary size at a given distance from a primary [6]; several parent craters likely contribute to the expansive rays and secondary crater chains observed, including Copernicus, Aristillus, Autolycus, Aristarchus, and in one case, Aristoteles. However, morphologic observations in LROC NAC images are required to determine whether the grouped craters have similar degradation states (same ages), because it is possible that the groupings are comprised of craters of different ages (non-obvious secondaries with younger primaries superposed). Nonetheless, measures of areal density aid in the identification and determination of non-obvious secondaries, and it is probable that at least some portion of the grouped non-overlapping craters represent far-flung, non-obvious secondaries, similar to those observed at Tycho [3] and Zunil [on Mars; 2].

Author: NOAH PETRO

Geology

ORAL

The Lunar Reconnaissance Orbiter – Highlights and Looking Forward

The Lunar Reconnaissance Orbiter (LRO) has been orbiting the Moon for five years. LRO science teams have delivered > 500 TB of data to the PDS, including higher-level data products (maps, mosaics, derived products), creating the largest single data archive for any NASA planetary science mission. Now, nearing completion of its first Extended Science Mission (ESM), LRO has proposed a second ESM (ESM2) in order to make new measurements in support of newly defined science questions. In addition to new science, LRO supports additional objectives that only LRO can currently provide, including the identification of safe landing sites for future landed missions, measurements that address Strategic Knowledge Gaps (SKGs), and can serve as a data relay for farside landers/rovers. In its current quasi-stable orbital configuration (polar orbit, ~30 x 180 km) LRO is capable of remaining in orbit for at least eight more years.LRO's seven instrument teams have been highly productive. Recent highlights include the identification of LRO-era impact craters, bi-static measurements of potential polar ice deposits, the variability of volatiles at and near the surface, and the variability of exospheric species. These recent discoveries form the core of LROs new objectives for the proposed ESM2. An overarching theme for ESM2 is change – on the surface, beneath the surface, and in the exosphere. The next two years of LRO operations will be an ambitious program of lunar and planetary science that are directly linked to the current Decadal Survey. Examples of the science LRO will address with 2 additional years of operations are given here. Evidence suggests that water molecules migrate across the lunar surface, LRO's ESM2 will characterize this water cycle on seasonal time scales with multiple instruments using innovative methods only recently validated. A surprising number of new impacts were recently detected. LRO will systematically survey these fresh impacts to determine their global abundance and the current flux of small meteorites while elucidating new information on impact dynamics. The thermal properties of the surface show unanticipated variability, particularly in the polar regions. We will employ new techniques to characterize the vertical as well as the horizontal structure of the regolith with never-before possible measurements. On the basis of innovative measurement approaches recently validated by LRO, a series of coordinated multi-sensor measurement campaigns will be used in ESM2 to address science questions associated with the Moon's interaction with the dynamic space environment.LRO continues to maximize its capabilities by operating in nadir and off-nadir modes. Off-nadir pointing has enabled new measurements by nearly all instruments and expands the range of science questions that LRO can address. For example, new off-nadir measurements by the LAMP instrument allow for a more detailed characterization of the exosphere. Also, off-nadir measurements by LROC, LAMP, and Diviner allow for broader phase angle coverage and thereby extends the photometric coverage of each instrument. These measurements are new to LRO and open up new avenues for understanding the Moon and airless bodies.

Author: NOAH PETRO
ORAL

Geology

Sampling Impact Melt From the South Pole-Aitken Basin and SPA Pre-Nectarian Basins

The South Pole-Aitken Basin (SPA), possibly the oldest lunar basin, contains an array of basin, crater, and volcanic deposits. For many years, the nature of regolith components has been modeled in order to predict their origin, both vertically and horizontally, on the crust (local vs. foreign, lower crust/mantle vs. upper crust). These modeling efforts have concluded that the non-volcanic components of the regolith within SPA is dominantly locally derived, containing SPA derived impact melt with a small component of possible mantle derived materials (derived from two, large basins within SPA over very thin crust). Apollo and Luna regolith samples inform us that the regolith at any location of the Moon contain a diversity of materials, both in time and composition. As Bottke et al. present at this meeting PreNectarian (pN) basins may have formed in a narrow window of time following the formation of the Moon and SPA. Here we assess the likely contribution of pN basin ejecta to SPA regolith. We consider the contributions to the regolith of five pN basins identified by Fassett et al (2012; JGR), four interior to SPA (Amundsen-Ganswindt, Poincaré, Ingenii, Apollo) and the Australe basin located exterior to SPA.Following the approach described by Cohen and Cooker (2010; LPSC) we evaluate the fraction of melt from pN basins as part of ejecta deposits that are incorporated into the SPA regolith. First we consider the ejecta from Australe, a heavily degraded 880 km diameter basin. Impact melt from the formation of this basin may extend as deep as ~190 km (Cintala and Grieve, 1998) and may comprise ~8% of its ejecta. Given that Australe may be extremely old (see Bottke et al., this meeting), its ejecta may be extremely diluted within the SPA regolith, or absent entirely if the crustal properties at the time of formation are as unique as Bottke et al. describe. The other four pN basins are located inside or on the rim of SPA (listed above). These basins range in diameter from 315-480km in diameter with depths of melting likely from 60-100 km depth (assuming impact velocities of 15-20 km/s; Cintala and Grieve, 1998). As Petro and Jolliff described in 2012, both Apollo and Poincare have extremely thin crust in their interiors, implying that their melt could be derived from within the mantle. The fraction of melt in their ejecta deposits from each these basins is ~5%, not a large volume, but when the total contribution of basin ejecta to SPA is small (Petro and Pieters, 2008), their contribution to the regolith is not-insignificant. A well selected sample-return site within SPA would allow access to both SPA impact melt as well as material that can constrain the “SPA impact chronology” including SPA, and post-SPA basins. These in turn are ideal locales to test hypotheses of early impact fluxes.

SSERVI-ESF14-103

Author: KENNETH RAMSLEY

POSTER

Geology

Impact ejecta from Mars to Phobos: Regolith bulk concentration and distribution, and the sufficiency of Mars ejecta to produce grooves as secondary impacts.

The surface of the martian moon Phobos is characterized by parallel and intersecting grooves that bear resemblance to secondary crater chains observed on planetary surfaces. Some researchers have hypothesized that Phobos grooves are produced by ejecta from martian primary crater impacts that intersects Phobos to produce parallel chains of secondary craters. To test this hypothesis we plot Keplerian trajectories of ejecta from Mars to Phobos. From these trajectories we: (1) set the fragment dispersion limits that are required to emplace the parallel grooves pits as observed in returned images from Phobos; (2) plot ejecta flight durations from Mars to Phobos; (3) map regions of exposure to secondary impacts and exposure shadows, and compare these to the observed grooves; (4) assess the viability of ejecta emplacing the large family of grooves covering most of the northern hemisphere of Phobos; and (5) plot the arrival of parallel lines of ejecta at oblique incident angles. We also assess the bulk volume of ejecta from large martian impact events and compute the total volume of Mars ejecta that intersects Phobos over geological time. On the basis of our analysis, we find that the predictions of this hypothesis (that Phobos grooves are produced by the intersection of ejecta from craters on Mars) are inconsistent with a wide range of Mars ejecta emplacement models and observations, and based on our analysis we conclude that the hypothesis is not valid. We also apply modeling methods that predict the flight of ejecta from Mars to Phobos to the question of the bulk concentration and distribution of Mars ejecta that is deposited in the regolith of Phobos. The gravity of Mars and the observation of a thick Phobos regolith suggests that nearly all ejecta from impacts on Phobos is inserted into temporary orbits around Mars and remains trapped in these orbits for several days to several hundred years until it re-impacts with Phobos to produce new generations of ejecta. Due to orbital mechanics, Phobos ejecta fragments typically re-impact on opposite hemispheres of Phobos from their previous impact sites, and when combined with the typical conical dispersion pattern of impact ejecta, this suggests that just two or three generations of re-impacts on Phobos are sufficient to uniformly disperse Mars ejecta fragments globally across the geographic surface of Phobos. For the present-day altitude of Phobos, we calculate a bulk concentration of Mars ejecta fragments in the regolith of Phobos of 250 ppm. Because Phobos has orbited at least 4,000 km farther from Mars during all but the most recent 500 Myr, this suggests that our prediction of 250 ppm for the bulk concentration of Mars ejecta will be found preferentially in the uppermost 0.5–1.0 meters of the Phobos regolith, and at depth, Mars ejecta fragments are likely to be found in bulk concentrations that are 10–60 x less than at the surface of Phobos.

SSERVI-ESF14-104

Author: DEANNE ROGERS

POSTER

Geology

Using a volcanic analog site to understand causes of spectral and thermophysical variability over extraterrestrial volcanic terrains

It is well documented that individual lava flows of differing age can be distinguished in infrared spectral imagery due to variations in oxidation coatings, depositional silica, glassy rinds and spallation, and texture. Aside from spectral variability due to geochemical processes, however, there are other factors, such as volcaniclastic sediment cover, microscale surface texture (vesicularity), and macroscale surface texture (flow morphology), which affect the spectral and thermophysical variability observed from orbit. Here we build upon previous work by investigating infrared spectral signatures from surface units in and around the December 1974 flow in the SW rift zone. This area allows us to sample relatively fresh flows, older flows, ash deposits and fumarole mineralogies, all which are distinguishable in remotely sensed infrared data sets. Our objective is to understand the dominant factors which might contribute to observed spatial variations in spectral and thermophysical properties on other planetary bodies at both the sample and unit (remotely sensed) scale. Thermal Infrared Multispectral Scanner (TIMS) data (8-12 μm, 2 m/pixel) acquired over the December 1974 flow were processed and spectral units were identified. During a field campaign conducted in April 2013, multiple samples were collected from units of differing age, textures and spectral properties, and photographs and thermal images were used to document the surface textures and temperatures at a macroscale. A principal components transform was applied to the TIMS data. The first principal component, which accounts for ~82% of the total variance in the scene, is controlled by relative areal abundance of ash deposits, which exhibit relatively low ~11 μm emissivity, versus exposure of the pahoehoe subunit of the 1974 flow, which exhibits relatively low ~9 μm emissivity due to thin silica coatings. Nearly all of the spectral variability in the study region can be described as a mixture of these two components. The second principal component, accounting for ~14% of the total variance, is dominated by elevational differences, arising from imperfect atmospheric correction. The addition of temperature information allows for additional discrimination between spectrally similar units; for example, the 1974 a'a subunit is spectrally similar to relatively unmantled, older undivided flows. However, daytime temperatures between the two units differ by >4 K. Field-based thermal imaging shows that this temperature difference is likely due to increased area of shadowed surfaces associated with the clinker morphology of the a'a subunit. Thermal emission spectra acquired from samples of each unit show that, despite varying geochemical processes affecting the surface colors and microscale textures, most samples are spectrally similar to opaline silica. The silica spectral signatures do not appear to vary with coating color or age of the flow, with essentially identical signatures observed for white, grey, and blue coatings, as well as for older undivided flows. The most significant spectral differences are between unconsolidated ash samples and lava flows. These results suggest that both geochemical and physical properties strongly affect the remote sensing-based interpretations, and that spectral and temperature information should be used in tandem to guide field traverses.

Author: M. ELISE RUMPF

Geology

ORAL

Thicknesses of Lunar Lava Flows: Comparison of Layered Mare Units with Terrestrial Analogs

The Lunar Reconnaissance Orbiter (LRO) Narrow Angle Camera (NAC) returns images with greater than 0.5 meter resolution, revealing layered deposits in the lunar maria. Many layers are interpreted to be sequences of basalt flows in the walls of impact craters and in pit craters, thought to be skylights above ancient lava tubes. Since the Apollo era, remote sensing and ground observations have estimated thicknesses of mare basalt flows to range from less than one meter up to 60 m or greater. Recently, thicknesses of individual layers measured using LROC NAC imagery of both pit craters and impact craters ranged from 2–14 m. Caution must be exercised in the interpretation of surface processes from morphologies of features that are close to the limits of resolvability because our knowledge of surface processes, including lava flow emplacement, on the Moon is not fully developed.We have conducted terrestrial analog studies to assess the accuracy of basalt flow thickness measurements in high-resolution lunar imagery. We mapped layered basalt flow sequences in valley walls in the Waiʻanae and Koʻolau Ranges of Oʻahu, Hawaiʻi, using WorldView-2 satellite images. Subsequent fieldwork allowed for validation of image interpretations through thickness measurements of in situ lava flows. Of the eight transects studied at three field locations, seven revealed WorldView-2 imagery average thickness estimates that were greater than average thicknesses measured in the field. Average image-derived to field-observed thickness ratios varied up to 6.3. A primary reason for this overestimation by remote sensing analysis is that many outcropping layers within a transect contain more than one individual flow, a distinction that is not visible in satellite imagery. The dense cores of ʻaʻ_ flows are commonly resistant to erosion and provide protection for underlying layers, particularly more easily eroded pahoehoe flows or ʻaʻ_ clinker, leading to single outcrops which contain several lava flow units.LRO NAC image measurements of layered mare basalts in the walls of impact craters provided flow thicknesses 2–5 times greater than those derived from images of the Oʻahu study sites. Lunar outcrops may contain more than one individual flow similarly to terrestrial outcrops, suggesting that estimates of lunar flow thicknesses are greater than actual flow thicknesses. Therefore, interpretations of lava flows in high-resolution lunar imagery may underestimate the number of flows present in a layered sequence and consequently overestimate the flow thickness. Current measurements of lava flow thicknesses derived from planetary images should be interpreted as maximum thicknesses. The accuracy of mare flow thickness measurements has broad implications for lunar exploration, for understanding of the thermal evolution of the Moon, and for the preservation potential of exogenous volatiles implanted in lunar paleoregoliths that were subsequently covered by active basalt flows.

Author: BHAIRAVI SHANKAR

Geology

ORAL

Exploring the North West Quadrant of the SPA basin

The South Pole-Aitken (SPA) basin is a top site for human and robotic lunar exploration as it can address questions including the solar system bombardment history, the effects of impact cratering, and the differentiation of planetary interiors. Several observations from orbit of diverse mineral assemblages derived from depth at SPA (including pure anorthosite, Mg-Spinel, and olivine-rich materials) has further fueled the interest to better SPA. Complex craters within SPA have the potential of sampling both crustal and mafic rich materials depending on their proximity to the basin interior. We look at several complex impact craters located along the north-west quadrant to address the potential sampling of SPA derived impact melt. A combination of spatial, spectral, and topographic datasets are used to assess the distribution of impactite materials of these craters. Birkeland crater, Eratosthenian aged, is 82 km in diameter with a well defined crater rim, terraced walls, and a flat crater floor. The central uplift is a consolidated peak with partial slumping along the north-east section. Previous studies have noted a strong thorium anomaly near Birkeland. O'Day crater, Copernican in age, is located north-west of Mare Ingenii and has a rim diameter of 71 km. The northern section of the crater floor is flat and filled with smooth materials. The southern section, in contrast, has a mixture of both smooth and rough deposits. The central uplift appears to be partially collapsed. The extent of impactite units are determined using optical data from the LRO NAC dataset. Impact melt deposits are identified primarily based on their visible characteristics (smooth surfaces, not associated with any volcanic source) using LRO-WAC global mosaics and individual NAC products. The crater floor at both craters is filled with large extents of smooth terrain, interpreted as impact melt rich deposits, and some hummocky terrain. Melts are observed along the terrace walls and overlying impact ejecta as pooled deposits within topographic lows. UV-VIS-NIR coverage from the Moon Mineralogy Mapper instrument is used to determine the compositional characteristics of the impactite units. Sampled spectral profiles indicate the presence of mostly noritic and gabbroic rock types at both craters with more mafic rich concentrations concentrated along the southern sections along both craters. The variable extent of mafic rich content within both Birkeland and O'Day allude to the variable stratigraphy in the target subsurface. The proximity of O'Day crater to Mare Ingenii may explain the concentration of mafic assemblages. Iron-poor compositions within the central uplifts at O'Day suggest the distribution of mafic rich materials is not completely continuous. The distribution of mafic rich units at Birkeland crater appear ambiguous. Proximity of these mafic rich areas to areas with thorium anomalies, and possible implications is currently being further investigated. Future work includes characterizing the texture and extent of impact melt deposits beyond the crater floor using Mini-RF data; and comparing the compositional observations to those within other areas of the SPA.

Author: ROBERT WAGNER

ORAL

Geology

Distribution, age, and formation mechanisms of lunar pits

Introduction: The Lunar Reconnaissance Orbiter Narrow Angle Camera (NAC) images the Moon with pixel scales of 0.5-2m. We systematically searched NAC images acquired with low incidence angles (0-50°) for vertical-walled collapse features using a semi-automated process. We located 231 pits, primarily in impact melts of Copernican craters [1].PitScan: We developed an algorithm (PitScan) to search for candidate pits. PitScan generally produces ~150 incorrect detections for each actual pit. In testing on images known to have pits, it missed 7% of mare pits and 40% of impact melt pits, the latter number likely due to the missed pits being below PitScan's minimum size cutoff.Pit discoveries: To date, we know of eight pits in mare basalt, two pits in highland terrain, and 221 pits in impact melt deposits of 29 craters. Three of the mare pits were previously known from the Kaguya mission [2]. The mare pits are spread across seven maria, and are mostly >40m across and >30m deep. The two highland pits occur north of Mare Serenitatis, and are 40-55m in diameter and ~25m deep. There is no compelling evidence for a tectonic origin for most mare and highland pits. A volcanic origin is possible for most of these pits, although only the Marius Hills pit is obviously related to volcanic processes.Impact melt pits are generally smaller than mare pits, with a median diameter of 16m and a median depth of 7m, and are frequently irregular in outline. Some much larger impact melt pits do occur, and are generally bowl-shaped, with diameters up to 900m and depths in excess of 100m. We interpret that void spaces in impact melt ponds likely formed as melt flowed after the surface solidified, perhaps due to isostatic adjustment of the ground beneath the melt pond and slumping of the crater walls.Age analysis: Neither the mare pits nor most of the impact melt pits are likely to have formed during the original emplacement of their host materials. From standard crater frequency distributions, craters near the mare pits should be in equilibrium at >200m [3], so small, crisp features such as these pits are very unlikely to have survived for >3 billion years. A similar argument holds for impact melt pits. King and Copernicus craters, with two of the highest pit concentrations, have melt pond crater equilibrium diameters of 30-50m [3,4]. Most of the pits on these melt sheets are <20m in diameter, indicating that they would likely have been destroyed had they formed at the same time as the melt pond. Most pits likely formed from recent impacts breaching thin sections in the roofs of pre-existing sub-surface voids.References: [1] Wagner, R.V. and Robinson, M.S. (2014) doi:10.1016/j.icarus.2014.04.002. [2] Haruyama, J. et al. (2010). 41st LPSC #1285. [3] Hiesinger, H. et al. (2012), doi:10.1029/ 2011JE003935. [4] Ashley, J.W. et al. (2012), doi:10.1029/2011JE003990.

Author: JENNIFER WHITTEN

ORAL

Geology

Lunar cryptomaria: The distribution and composition of ancient volcanic deposits on the Moon

The Moon has been affected by volcanism during the first half of its history. Most of these volcanic deposits are concentrated on the nearside and have crater retention ages that cluster around ~3.6 Ga. The age distribution of volcanic deposits suggests there was a sharp increase in the number of volcanic deposits beginning around 3.9 Ga, with few older deposits. Is this observation due to the lack of ancient volcanic deposits? Or is this gap between the formation of the anorthosite crust and the onset of observed mare volcanism due to limited preservation? In this study we strive to address this fundamental question and investigate what the distribution and mineralogy of ancient volcanic deposits reveal about the early thermal history and evolution of the Moon. Light plains are smooth high albedo surfaces that can be produced from basin impact ejecta ponding in topographic lows and by similar processes covering ancient mare deposits, creating cryptomaria. Cryptomaria are lunar volcanic deposits that have been covered with a layer of high albedo ejecta and have a similar morphology to impact-produced pre-mare Cayley Plains. In this study, we use a variety of remote data sets from the Lunar Reconnaissance Orbiter (e.g., Lunar Orbiter Laser Altimeter (LOLA), Diviner, Lunar Reconnaissance Orbiter Camera (LROC)) and Chandrayaan-1 (Moon Mineralogy Mapper (M3)) in order to assess the distribution and mineralogy of ancient cryptomaria as well as to identify criteria to distinguish cryptomaria from Cayley Plains produced solely by impact processes. M3 VNIR spectroscopic data were used to identify high concentrations of dark-halo craters (DHC) superposed on light plains. This type of occurrence of DHC, small impacts ~5-10 km in diameter that excavate low albedo material from beneath a high albedo surface, indicate the presence of a buried volcanic deposit beneath a high albedo surface. Mosaics of optical period 2c1 were produced with a resolution of 140 m/pixel. Approximately 30 different suspected regions across the Moon were analyzed for the presence of cryptomaria. From these 30 regions, only 18 were positively identified to contain cryptomaria on the basis of the presence of DHC. Once the cryptomare were mapped, other datasets such as topography, surface roughness, and rock abundance were used to characterize the surfaces of cryptomaria and the global distribution of Cayley Plains. M3 3x3 average spectra were collected from DHC and then processed using the Modified Gaussian Model to determine the pyroxene compositions of cryptomaria. Identified cryptomaria are concentrated around the nearside maria, especially in the eastern hemisphere. The most useful criterion for distinguishing between cryptomaria and end-member impact-produced Cayley Plains is a high concentration of DHC with a basaltic mineralogy. Analysis of the M3 spectra indicates that the mineralogy of all identified cryptomaria are consistent with mare basalts. These findings suggest that mare basalt volcanism was occurring prior to 3.9 Ga and that mantle dynamics and crustal thickness variations controlling the eruption of magmas onto the surface was in place during the emplacement of cryptomaria.

Author: SANDRA WISEMAN

POSTER

Geology

Aristarchus Olivine in Context With Circum-Imbrium Olivine-Bearing Deposits

The Aristarchus region contains geologically diverse deposits and the Aristarchus impact crater, located on the SE margin of the plateau near the contact between plateau materials and western Procellarum basalts, has exposed materials with diverse compositions. Of particular interest is the origin of olivine-bearing deposits that occur on the SE portion of the crater rim and ejecta. NW portions of the rim and ejecta expose plateau materials and are spectrally dominated by pyroxene in the VNIR. Spectra of the NW rim and ejecta are consistent with a noritic composition and with the inferred origin of the plateau as uplifted upper crust. Therefore, it is unlikely that the olivine- bearing materials, which exhibit a strong 1 micron olivine absorption and only minor pyroxene contributions in Chandrayaan-1 M3 spectra, are derived from plateau crustal materials similar to those exposed in the NW portion of the crater. Pyroclastic deposits on the plateau exhibit subtle glass features that are distinct from olivine. Plagioclase is exposed in the crater's central peak. Bright material in the crater's SW ejecta was inferred to be highly silicic in nature due to short CF positions identified in LRO Diviner data. Based on the geologic context, it is likely that the olivine-bearing ejecta is mixed with spectrally featureless plagioclase. Diviner data of the olivine-bearing material observed with M3 are consistent with a mixture of olivine and other shorter CF phases.The olivine-bearing deposits could be derived from a shallow pluton that is not represented by other surface exposures (perhaps related to the formation of the plateau and/or pyroclastic deposits) or re-excavated material originally deposited by the Imbrium forming event. As the olivine is associated with impact glass, melt and ejecta, impact processes may have played a role in its formation. Several olivine-bearing deposits have been detected in the vicinity of Imbrium. Such deposits may have been excavated from the lower crust or possibly upper mantle. There are several olivine bearing deposits in the vicinity of Imbrium. We investigated these deposits and looked for additional deposits using M3 data. Some of these deposits are spectrally dominated by olivine, although the spectra are not as spectrally pure as the Aristarchus olivine-bearing spectra. This may be because the deposits are smaller and thus more likely to be spatially mixed with other material. Given that spectrally similar deposits to those of the olivine-bearing Aristarchus ejecta are found in other exposures in the vicinity of Imbrium, the deposit in Aristarchus may represent re-exposed Imbrium ejecta.In order to differentiate between these hypotheses, we are integrating spectral data in the UV/VIS (LRO WAC), VIS/NIR (Chandrayaan-1 M3), and TIR (LRO Diviner) to further characterize the assemblages of minerals that occur in association with the olivine-bearing deposits in Aristarchus crater, western Procellarum.

SSERVI-ESF14-110

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ORAL

Geology (Including Petrology)

mineral exploration on mars

On Earth there is an association between 50 to 300 km. diameter multi-ring impact craters and mineral deposits containing nickel, copper, gold, platinum, and uranium. The deposits tend to occur along the outer rings of the craters. Examples are the nickel-copper deposits at Sudbury, Canada and the uranium deposits in the Athabaska basin, Canada.Mineral exploration on Mars is proposed in the outer rings of multi-ring impact craters. The firsts stage in the detection of deposits would be ground geophysical surveys using magnetic, electromagnetic and radiometric detectors.

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ORAL

Geology (Including Petrology)

Thermoluminescence Dating of Volcanism on Hawaii: Present Status and Future Prospects

Volcanism on the Big Island of Hawaii covers a timespan from the present to over a million years. Historic records and radiocarbon methods date the younger periods of activity, and K-Ar derived methods are especially effective for the older periods of activity. Between these limits, which includes much of the activity for Mauna Kea and Mauna Loa, thermoluminescence dating has often been proposed. Thermoluminescence, literally the light emitted when a sample is heated, records the number of electrons that have been excited to traps ~1 eV below the conduction band in a non-conducting crystal lattice, such as many silicates. The excitation is caused by the absorption of ionizing radiation and is therefore time-dependent. Thus the strength of the TL signal is proportional to absorbed dose. Since the dose-rate can be measured directly with dosimeters (such as those used in health physics) or estimated from the composition of the samples, it is possible to divide absorbed dose by dose rate to calculate age. Several authors have reported various degrees of success in applying this method. The major complication is the stability of the electrons trapped. Electrons released at low temperatures during heating are in shallow traps which may have been drained at ambient temperatures since eruption. However, methods have been found for identifying thermally stable traps – derived from TL pottery dating methods – and these are generally successful. More problematic is a form of instability displayed by volcanic lavas which is that they tend to "leak" electrons from the traps. The process is called "anomalous fading" and it is an instability that is difficult to correct for.I propose an alternative method of using TL to obtain ages for lavas in the 50,000-1,000,000 year range that is not subject to these complications. Instead of using the natural ("as is") TL signal, the sample has its natural TL removed (by heating to 500oC, for instance) and then exposed to ionizing radiation in the laboratory. The induced signal is a measure of the amount of crystalline phosphor (the mineral producing the TL, in this case feldspar). Literature data suggests that fresh lavas have a low induced TL (also referred to as "artificial TL", or, better, "TL sensitivity") and that the induced signal increases with time as feldspathic glass is converted to crystalline feldspar. With suitable laboratory calibration, I suggest that it should be possible to obtain a "crystallization age" that would reflect the time since the eruption of these lavas and cover a time-span not readily accessible by K-Ar and radiocarbon.We appreciate support for this work from NASA's SSERVI through the FINESSE (PI, Jennifer Heldmann) and RISE4E (PI, Timothy Glotch) teams.